NAVAL WAR COLLEGE
Newport, R.I.

AN EXAMINATION OF THE JOINT DIRECT ATTACK MUNITION (JDAM) IN THE CONTEXT OF NETWORK-CENTRIC WARFARE (NCW): ENORMOUS POTENTIAL AND ALARMING PITFALLS.

by

Douglas M. Larratt
LCDR USN

A paper submitted to the Faculty of the Naval War College in partial satisfaction of the requirements of the Department of Joint Maritime Operations.

The contents of this paper reflect my own personal views and are not necessarily endorsed by Naval War College or the Department of the Navy.

Signature:

5 February 2001

Capt. J. Fitzsimonds, USN
Lt.Col. J. Dill, USAF
Prof. R. Reilly

Abstract

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The Joint Direct Attack Munition (JDAM), having recently completed operational evaluation and been employed in Operations ALLIED FORCE and SOUTHERN WATCH, is one of these systems. By examining JDAM in the context of Network-Centric Warfare concepts, three results are achieved:

- Optimization of the JDAM system;
- Validation (or non-validation) of the Network-Centric Warfare concept;
- Identification of potential pitfalls in the Network-Centric Warfare concept.

JDAM holds enormous potential in the Joint Vision 2020 operational concept of Precision Engagement. Conversely, JDAM's shortcomings, although in the process of being remedied, identify some alarming pitfalls in the transformation to network-centric operations and hold some important lessons for the modern warfighter implementing this revolutionary concept.

6 NWC.R. A

UNCLASSIFIED

REPORT DOCUMENTATION PAGE

1. Report Security Classification: UNCLASSIFIED	
2. Security Classification Authority: N/A	
3. Declassification/Downgrading Schedule: N/A	
4. Distribution/Availability of Report: DISTRIBUTION STATEMENT A: APPROVED FOR PUBLIC RELEASE; DISTRIBUTION IS UNLIMITED.	
5. Name of Performing Organization: JOINT MARITIME OPERATIONS DEPARTMENT	
6. Office Symbol: C	**7. Address:** NAVAL WAR COLLEGE 686 CUSHING ROAD NEWPORT, RI 02841-1207
8. Title (Include Security Classification): AN EXAMINATION OF THE JOINT DIRECT ATTACK MUNITION (JDAM) IN THE CONTEXT OF NETWORK-CENTRIC WARFARE (NCW): ENORMOUS POTENTIAL AND ALARMING PITFALLS (U)	
9. Personal Authors: LCDR Douglas M. Larratt USN	
10. Type of Report: FINAL	**11. Date of Report:** 5 February 2001
12. Page Count: 27	
13. Supplementary Notation: A paper submitted to the Faculty of the NWC in partial satisfaction of the requirements of the JMO Department. The contents of this paper reflect my own personal views and are not necessarily endorsed by the NWC or the Department of the Navy.	
14. Ten key words that relate to your paper: network-centric warfare, precision engagement, precision guided munitions, GPS, targeting	

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16. Distribution / Availability of Abstract:	**Unclassified**	**Same As Rpt**	**DTIC Users**
	X		
17. Abstract Security Classification: UNCLASSIFIED			
18. Name of Responsible Individual: CHAIRMAN, JOINT MILITARY OPERATIONS DEPARTMENT			
19. Telephone: 841-6461	**20. Office Symbol:** C		

Security Classification of This Page UNCLASSIFIED

Table of Contents

Introduction

The Network-Centric Warfare (NCW) concept offers tremendous potential for U.S. military combat effectiveness in this new century. Its proponents have pre-ordained NCW as the modern revolution in military affairs (RMA)[1] and assert its inevitability in the modern age of information technology. The principal question for these proponents is not if the NCW RMA will evolve, but when it will occur, and who will best be able to capitalize on its revolutionary impact? The theorists have written much, mostly in broad, conceptual terms. Vice Admiral Arthur K. Cebrowski, a leading proponent of NCW, states,

> 'Network-Centric Warfare is a concept. As a concept, it cannot have a definition, because concepts and definitions are enemies. Concepts are abstract and general, while definitions are concrete and specific.'[2]

Those who would constrain this dynamic and rapidly evolving concept with definitions become its enemies. However, validation of NCW and the realization of its increased combat effectiveness require detailed analysis of NCW concept application to specific military operations. In applying the NCW concept to a specific operational concept, Precision Engagement, and a specific new technology weapon system, the Joint Direct Attack Munition (JDAM), three results are achieved:

(1) Optimization of the examined system and operational concept;

(2) Validation (or non-validation) of the NCW concept;

(3) Identification of potential pitfalls in the NCW concept.

The recently introduced Joint Direct Attack Munition (JDAM) is expected to become the principal air-to-ground, guided munition in the United States arsenal. A planned buy of 87,000 guidance kits through 2007[3] will result in its replacement of the Laser-Guided Bomb (LGB) (approximately 63,000 unit inventory in 1995)[4] as the principal Precision Engagement

weapon. By design, it is a very simple and low cost weapon, combining a pre-existing conventional warhead (the identical warhead of an LGB) with a GPS (Global Positioning System)-aided inertial guidance system. When released from an aircraft, the JDAM tracks and updates its position using the GPS-aided inertial navigation, guiding autonomously to a pre-designated absolute coordinate position.

JDAM is simple, inexpensive, reliable[i], and effective. More importantly for the purposes of this examination, JDAM is inherently "network-centric" by nature. Plainly stated, JDAM relies on a "system of systems" for basic function. This system dependence includes reliance on:

- An independent targeting system (not organic to the aircraft) for highly accurate geodetic coordinates;
- A constellation of GPS satellites continuously transmitting an encrypted time signal for ranging;
- A surveillance system for post-strike Battle Damage Assessment (BDA).

In contrast, the LGB has a more "platform-centric" nature where most of its systems required for function (e.g. FLIR[ii] sensor, laser designator, mission recorder) are organic to the aircraft delivery platform.[iii]

The following analysis focuses exclusively on documented and known JDAM issues and shortcomings identified through operational evaluation, experimentation, and initial

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[i] The assertion that JDAM is reliable is arguable since it failed to meet its mission reliability requirement during operational evaluation. (Requirement = 90%, Tested Mission Reliability = 89% as reported in the JDAM Opeval Final Report) Deficiencies were identified and are in the process of correction; meaning mission reliability should only improve. The key point is JDAM's demonstrated mission reliability is better relative to other more complex guided munitions.

[ii] Forward-Looking Infrared

[iii] The implication is not that LGBs are incompatible with NCW concepts, rather that JDAM, due to its reliance on external systems, has more compatibility with NCW concepts.

operational employment in Operation ALLIED FORCE (OAF) and Operation SOUTHERN WATCH (OSW). The results are insightful. First, the JDAM system is on an optimization path with enormous potential to fulfill the objectives of the Precision Engagement concept. Second, Network-Centric Warfare is a valid concept with the potential for substantial increases in combat effectiveness. Lastly, great caution is advised in the progressive transformation to a network-centric force structure. Pitfalls exist in the transition to and conduct of network-centric operations, which if not addressed, expose the force to significant vulnerability and potential mission failure. These pitfalls include:

- Non-redundant critical nodes;
- Erroneous information in the network;
- Immature key nodes;
- Immature links;
- Lost accountability.

The challenge for the network-centric warfighter in the transformation is to understand these pitfalls and aggressively minimize or eliminate them through a deliberate strategy of analysis, experimentation, and organizational and doctrinal development. Only then will the enormous potential of Network-Centric Warfare be realized.

What are Network-Centric Warfare and Precision Engagement?

The NCW concept postulates that information technology and the shift in focus from platforms to networks will revolutionize the modern battlefield. A network consists of nodes, systems performing sensor, engagement, and C^2 functions, and the links among them. The network enables the sharing of information and assets.[5] The network-centric force has a

faster, more effective warfighting style characterized by speed of command and self-synchronization.[6] Speed of command has three sequential parts: (1) achievement of information superiority and therefore battlespace awareness, (2) action with speed, precision, and reach to achieve massing of effects, and (3) foreclosure of enemy courses of action and enemy "lockout" due to the shock of closely coupled events.[7] Additional realized advantages are geographic dispersal of forces to minimize vulnerability and reduced battlespace footprint to decrease logistic requirements.

The Chairman of the Joint Chiefs of Staff vision for the U.S Armed Forces, the white papers "Joint Vision 2010" (JV2010) and its successor "Joint Vision 2020" (JV2020), are laced with NCW themes and concepts. JV2010 identifies four new operational concepts: "Dominant Maneuver", "Precision Engagement", "Focused Logistics", and "Full Dimensional Protection". These operational concepts are applied interdependently and enhanced by "Information Superiority" to ultimately achieve "Full Spectrum Dominance".

All of the new operational concepts have validity and importance, however it is critical to identify Precision Engagement as the principal instrument of force in the JV2010 template. Precision Engagement stands as the fundamental link to operational success, as it alone describes how effects are massed to achieve desired results. The remaining operational concepts, Dominant Maneuver, Focused Logistics, and Full Dimensional Protection, have import, however they serve only to facilitate the application of Precision Engagement.

Precision Engagement articulates a plan to achieve the critical NCW principle of "speed of command". It prescribes a process of rapidly and knowledgeably employing effects-based engagement to cause adversary "lockout". As defined in JV2020, the Precision Engagement sequence is: (1) location, surveillance, discernment, and tracking of targets;

(2) selection, organization, and use of correct systems; (3) generation of desired effects; (4) assessment of results; and (5) reengagement with decisive speed and overwhelming operational tempo as required.[8] How does JDAM fit into this concept? An understanding of JDAM's evolution and functional capability is first required.

JDAM Evolution: A Lesson of Desert Storm

The requirement for JDAM arose out of a need identified by the Air Force during Operation DESERT STORM for an adverse weather capable, air-to-ground guided munition.

During DESERT STORM, 227,000 conventional, deep attack munitions (approximately 17% of the current U.S. arsenal) were employed. Guided munitions represented only eight percent (some 18,000 weapons) of the deep attack munitions employed. Only half of these, approximately 9,000 weapons, were laser-guided bombs (LGBs)[9]. Most of the weapons employed (92%) were "dumb", free-fall conventional warheads and cluster munitions. Reasons for the limited employment of LGBs included limited LGB-capable delivery platforms, inventory limitations, and non-permissive weather. Although LGBs represented a significant improvement in effectiveness[10] over unguided munitions, the operation reinforced the existence of known LGB constraints.

> '...the effectiveness of airpower in Desert Storm was inhibited by the aircraft sensors' inherent limitations in identifying and acquiring targets...Pilots noted that IR, EO, and laser systems were all seriously degraded by clouds, rain, fog, smoke, and even high humidity...'[11]

This occurred in a region where low cloud ceilings historically existed only 9%[iv] of the time.[12] Environmental factors as well as system reliability and delivery profile constraints,

[iv] For reference, comparable low cloud ceiling percentages for Beirut, Osan, and St. Petersburg are 17, 33, and 64 respectively.

served to reduce mission success rates, requiring repeat missions and multiple weapons for single targets.

Weapon cost was also identified as an independent, constraining factor in Desert Storm. In post-conflict cost analysis, GAO identified that, "Although only 8 percent of the munitions used against planned targets were guided, they represented approximately 84 percent of the total cost of munitions."[13] This statistic is skewed by the very high cost of standoff precision weapons (e.g. TLAM). However, GAO also computed an approximate ratio of LGB cost to equivalent unguided warhead cost as 47:1.[14] Weapon cost versus mission success might be a more telling statistic, however this could not be determined from existing data. The critical point remains that in this major operation, weapon cost (and available inventory) was a factor in munition selection for DESERT STORM campaign commanders.[15] LGBs contributed substantially to the success of the air operation, but they were not the panacea that many perceived.

The JDAM Mission Need Statement (MNS) for an adverse weather-capable, low cost guided munition was approved in 1992. The JDAM Operational Requirements Document (JORD) was approved in 1996, articulating specific requirements for a low cost, strap-on GPS-aided inertial guidance kit for existing inventory 1000 lb (Mk 83/BLU-110) and 2000 lb (Mk 84/BLU-109) warheads. The JDAM system was to achieve "accurate" (13 meter CEP[v]) vice "precise" (3 meter CEP) guidance due to the physical accuracy limits of GPS. A second development phase, the JDAM Product Improvement Program (PIP) was to achieve "precise" guidance using an autonomous, terminal seeker.

[v] 13 meter CEP (circular error probable) implies a weapon impacts inside a circle of 13 meter radius 50% of the impacts.

JDAM Development, Employment, and Status Today

Through a competitive and streamlined acquisition process, the JDAM design met stated operational requirements while achieving an actual production cost of $18,000/unit;[16] well below the target of $40,000/unit.

Several key JDAM design features require identification for the purposes of this analysis. First, JDAM is dependent on highly accurate target coordinates derived from an electronic database of geo-coded, high-resolution, stereo imagery. Aircraft organic sensors (e.g. radar, FLIR) are not capable of achieving the coordinate accuracy for JDAM employment with minor exceptions. Second, JDAM requires the delivery aircraft to provide very accurate GPS-aided inertial navigation data to "tune out" errors in its lesser quality inertial system. Lastly, at release JDAM flies an autonomous, optimized profile to its target coordinate, first using inertial guidance only and sequentially acquiring GPS C/A code and encrypted GPS P code, before shifting to GPS-aided guidance.

JDAM completed an operational evaluation from July 1998 through November 2000 in which 132 JDAM's were released from B-52 and F/A-18C/D aircraft. JDAM significantly exceeded accuracy expectations, achieving an overall 8.7 meter CEP which included an arbitrarily inserted error for assumed target coordinate inaccuracies[vi]. Assuming perfect target coordinate data, in other words, without the arbitrarily inserted error, the JDAM achieved a CEP of less than 5 meters.[17] With this demonstrated performance, target coordinate accuracy has become the primary limiting factor in overall JDAM accuracy.

Coincident to the operational evaluation, Operation ALLIED FORCE erupted from March to June of 1999 as a major NATO air operation to control Serbian aggression and

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[vi] The JDAM Requirement assumed an arbitrary target location error (TLE) of 7.2 meter CEP to define overall accuracy of 13 meters CEP. Actual capability of targeting systems is classified.

genocide in Kosovo. From a meteorological standpoint, Serbia presented a significantly less permissive LGB environment than Iraq. With cloud cover greater than 50% more than 70% of the time, air strikes were impeded 54 of the 78 days of the operation[18]. Low rate initial production (LRIP) JDAM weapons were accelerated for the B-2, the only aircraft certified to operationally employ JDAM at the time. Over the 78 day operation, 45 B-2 sorties delivered 656 JDAMs on critical targets in the Federal Republic of Yugoslavia[19]. JDAM was highlighted as a major success of the operation.

Most recently since November 1999, JDAM has been successfully employed operationally from F/A-18s against targets in Operation SOUTHERN WATCH (OSW). JDAM has been successfully fielded. It awaits Milestone III (full rate production) decision scheduled for April 2001. JDAM is poised for full integration into our force structure. How will this inherently network-centric system be adapted into a force transforming to the Precision Engagement operational concept?

JDAM and Network-Centric Warfare: Enormous Potential

JDAM exists as one lethal engagement option in a menu of numerous lethal and non-lethal options for the Precision Engagement concept. However, its potential is significant when examined in the context of such NCW concepts as speed of command, massing of effects, dispersal of forces, small battlespace footprints, decisive speed, and overwhelming operational tempo.

JDAM achieves these grand NCW concepts simply by functioning as an economical force multiplier. This characteristic is supported by three factors: (1) a capability to

prosecute multiple DPIs (desired points of impact) per aircraft sortie; (2) the flexibility of employment from multiple redundant platforms; and (3) excellent mission reliability.

The first two listed characteristics enable sheer volume of accurate weapon deliveries at "overwhelming operational tempo". First, because each JDAM guides autonomously to a separately programmed DPI, releases of multiple weapons against discrete targets are possible for each aircraft sortie. An F/A-18 may prosecute up to four independent DPIs on a single sortie; a B-1, up to 24. Second, JDAM is integrated on a wide range of delivery platforms. A FLIR/Laser system is no longer required for guided munition capability; hence previously non LGB-capable platforms such as B-2, B-1, and B-52 now provide a high volume guided munition capability. Incorporation of the strategic bomber force increases weapon delivery volume and enables further geographic dispersal of forces.

The third characteristic, excellent mission reliability, results in an unprecedented rate of mission success for assigned DPIs. JDAM's mission reliability is significantly better than existing systems' reliabilities. Improved mission reliability is achieved through: (1) the flexibility of function in adverse weather conditions; (2) the simplicity of an autonomous guidance profile that relieves the pilot of the tasks and vulnerability of target location, identification, and post weapon-release man-in-the-loop tracking; and (3) the inherent physical reliability of a simple functional design. During operational evaluation, JDAM demonstrated a mission reliability rate of 89%[20]. In contrast, a GAO study of F-117 LGB performance during the Gulf War calculated 41 to 60 percent hit rate per tasked weapon (including weather aborts)[21] while achieving a weapon CEP of 13 meters.[22] The F-117's Desert Storm performance was arguably the most effective strike mission success rate in modern combat to date. While operational evaluation is not directly comparable to combat

operations, the percentages indicate that JDAM is capable of a substantial improvement in mission reliability.

In principle, JDAM now offers an unprecedented capability for accurately massing lethal effects in time and space by virtue of multiple DPI/multiple aircraft capability and significantly enhanced mission reliability. Forces are geographically dispersed between carrier-based strike aircraft, expeditionary tactical aircraft, and long-range strategic bombers. Improved weapon reliability and reduced launch platform requirements reduce logistic footprints. JDAM has enormous potential to support the operational concept of Precision Engagement and achieve the speed of command necessary to cause adversary "lockout".

JDAM's network-centric nature enables its enormous promise. Its dependence on other systems in the network facilitates its rapid and efficient employment. Conversely, this dependence also exposes the system to serious vulnerabilities. Whether JDAM's potential is realized depends directly on how effectively supporting systems required for JDAM function are evolved to support Precision Engagement and take advantage of NCW concepts.

JDAM and Network-Centric Warfare: Alarming Pitfalls

Most are familiar with the popular Walmart analogy of network-centric retailing. To outperform its competitors, Walmart shifts to network-centric operations and implements an IT-based operational architecture of a sensor grid, a transaction grid, and an information backplane. The sale of a light bulb detected in Muskogee triggers in real time the manufacture of a new light bulb at the supplier's plant in Peoria. Transaction and trend data are stored in the backplane. Awareness is raised. Self-synchronization occurs. The retailer responsively meets demand while minimizing costs. The company profits.[23]

The analogy indicates the enormous potential of network-centric operations for military applications. However, at some level the parallels between retail competition and modern warfare end. The dynamics, uncertainties, and symmetry of competition are significantly different and the ramifications of failure are far more severe. A peer competitor in the retail world is not likely to physically hard-kill a critical information node in the network or deliberately transmit interference into the links to degrade communications. If he did, what would be the worst-case result: a 4,000 light bulb overstock in Muskogee? The consequences of going out of business are far less severe than the consequences of losing a modern war. Final validation of NCW concepts can only occur through their direct application to modern warfare cases. The JDAM Precision Engagement case provides an opportunity for validation.

Although JDAM has demonstrated operational success through several years of operational testing, employment in two major operations, and evaluation in a recent Fleet Battle Experiment (FBE), numerous failures, shortcomings, and weaknesses of the JDAM system have been identified. Most issues are actively being rectified. Analysis of these deficiencies enables their categorization into several general themes linkable to the NCW concept. These themes articulate some alarming pitfalls in the transformation to an NCW force.

<u>Pitfall #1: Non-redundant critical nodes</u>. The existence of non-redundant critical nodes on which other systems depend for function is an extreme vulnerability. GPS is that critical node for JDAM. The GPS satellite constellation must be operational for JDAM to function. As stated previously, the JDAM delivery platform must continue to track a GPS-aided inertial navigation solution to "tune out" inaccuracies in the JDAM inertial

system. Otherwise, the weapon will fail to guide. A hard kill of the GPS constellation or high power jamming sufficient to deny GPS to the delivery platform is sufficient to cause JDAM mission failure.

A less severe and more expected condition is the presence of localized low power jamming, which denies JDAM acquisition of the GPS signal during free fall. This condition only results in a relatively minor degradation in JDAM performance due to JDAM's inertial guidance capability. In operational evaluation JDAM achieved a 12.4 meter CEP with inertial guidance vice an 8.7 meter CEP with GPS aided guidance.[24]

Awareness of GPS vulnerability has grown in recent years as GPS dependence has permeated many elements of the U.S. force. GPS is highly susceptible to jamming due to the relative low power of the signal and the necessity of simultaneously tracking four separate satellite signals to achieve a navigation solution. Improved security, satellite and system revisions, and development of jam resistant technology (in both receiver and antenna design) have evolved to reduce vulnerability. Aircraft capable of delivering JDAM are gradually incorporating more jam resistant navigation systems. For the JDAM weapon, the contractor has developed and demonstrated a jam resistant receiver[vii], however the receiver has not been incorporated in the design to date most likely for cost-benefit reasons.[25]

These actions reduce vulnerability, yet the fact remains the GPS node[viii] is: (1) not redundant and (2) critical to JDAM function. The GPS node is a single point kill for the JDAM system. This vulnerability is amplified by the migration of most of our guided munition inventory and delivery platforms to GPS dependence. The operational commander

[vii] Anti-Jam GPS Technology Flight Test (AGTFT).

[viii] The GPS constellation is characterized in this case as a single node for its potential vulnerability as a complete system. System vulnerability is reduced due to the existence of 24 satellites. The loss of one satellite would not seriously degrade system performance. Other potential means may exist to defeat the system.

must understand the vulnerability of his forces to GPS denial and hold contingencies for worst-case scenarios. The network-centric warfighter must be vigilant in screening systems and processes for critical, non-redundant nodes in the transformation to a network-centric force. The natural interdependence of network-centric platforms is a blessing and a curse: it can breed both redundancy and critical vulnerability into the system.

Pitfall #2: Erroneous information in the network. The insertion of erroneous information in the network, by either inadvertent or deliberate means, can have disastrous effects. The most visible recent manifestation of erroneous information flowing in the "targeting network" was the bombing of the Chinese Embassy during Operation ALLIED FORCE. DoD's After Action Report to Congress on Kosovo/Operation ALLIED FORCE reports,

> 'The bombing of the Chinese Embassy in Belgrade was entirely unintended. It was the result of a failure in the process of identifying and validating proposed targets. The headquarters of the Yugoslav Federal Directorate of Supply and Procurement (FDSP)) was a legitimate military target, but the technique used to locate it was severely flawed. None of the military or intelligence databases used to validate targets contained the correct location of the Chinese Embassy. Nowhere in the target review process was a mistake detected.'[26]

One might argue this incident was independent of the particular weapon employed. This argument misses the point entirely. The Precision Engagement concept, with its "effects based targeting", "decisive speed", and "overwhelming operational tempo", command a targeting process to be rapid, extremely intelligent, and absolutely accurate. Unchecked erroneous data on the network can quickly precipitate a series of undesired actions with potentially disastrous effects. The imperative for "decisive speed", coupled with a weapon system with unprecedented capability to rapidly engage a high volume of DPIs, places enormous pressure on the targeting process.

An additional identified characteristic of JDAM, though not evident in the embassy bombing, warrants further discussion. With relief from the traditional requirement for pilot target location and identification, the JDAM delivery profile is more flexible, tactical, and survivable but also more susceptible to target coordinate errors. The pilot no longer provides the final quality assurance for the targeting solution. Some operational commanders have ordered pilot identification of targets for this specific reason. In adverse weather or for non-FLIR capable aircraft, pilot identification is limited to a high-resolution radar picture allowing only verification of relative target position in the environment vice actual visual identification. In multiple weapon attacks against independent DPIs, identification of all aim-points is improbable and unfeasible. In this absence of pilot "quality assurance", target coordinate errors are more likely to become cases of collateral damage, fratricide, and mission failure. Test, development, and experimentation with the targeting process has identified weaknesses and error-prone processes and yielded continued progress in target coordinate quality. However, a "zero defect" process ensuring no erroneous data on the "targeting network" will not occur for some time.

We are left with the issue of erroneous data on the network. For the JDAM user, there is a continued effort to ensure the accuracy and quality assurance of the target coordinate development process. For the network-centric warfighter, erroneous data on the network poses a formidable problem. "Shared awareness" of erroneous information can cause all actors on the network to maneuver to a vulnerable position or result in an undesired effect. The erroneous data may not be simply inadvertent, as sizeable incentive exists for an adversary to deliberately attempt insertion of erroneous information. The network-centric concept promises both quicker reaction and increased awareness. However, these two

characteristics can be mutually exclusive. One characteristic may be traded to achieve the other. The challenge for the network-centric warfighter is capitalizing on the opportunity for quicker reaction while minimizing vulnerability to erroneous information. Processes must be exhaustively tested to ensure information quality and install safeguards to reduce vulnerability.

Pitfall #3: Immature Key Nodes. A network-centric weapon system, dependent on multiple other nodes (i.e. systems) on the network for success, can be degraded or neutralized if a key node is immature. The result of an immature key node is untimely, ineffective, or erroneous information. The targeting and BDA processes represent immature nodes upon which JDAM depends for success in the Precision Engagement concept.

Considerable effort has been focused on developing these immature processes. The Naval Warfare Development Command's (NWDC) Fleet Battle Experiment Bravo (FBE-B) "Silent Fury" of August-September 1997 was dedicated to the JV2010 Precision Engagement operational concept, specifically addressing Joint Task Force (JTF) targeting of GPS-Guided Munitions (GGMs).[27] "Silent Fury" results, as well as lessons learned from Operation ALLIED FORCE, have contributed significantly to shortening and enhancing the effectiveness of the Precision Engagement process. Systemic chokepoints, error-inducing linkages, and ineffective process steps have been identified and are changing. However, the change process is time-consuming. The primary joint doctrine publications for targeting and intelligence support for targeting, JP 3-60 and JP 2-01.1, have been in draft for several years.

Optimization of these processes is more than an exercise in new technology application and hardware acquisition. In fact, the key factors in process optimization have been changes in organization and doctrine. An excellent example of this is the BDA process.

The Kosovo After Action report identifies the JDAM system's lack of ability to provide Phase I BDA;

> '...munitions such as JDAM that do not incorporate a real-time imagery loop and will be used in much greater numbers in the future will complicate the damage assessment process.'[28]

The issues are not simply about what the surveillance assets are technologically capable of, or how many are available, but more importantly how effectively the existing assets can be organized, prioritized, scheduled, and tasked to achieve desired, timely BDA results. "Old ways of doing it" must be reevaluated in view of new capabilities and requirements. For example, given JDAM's demonstrated mission reliability, consideration should be given to basing Phase I BDA assessments on a pilot's recording of valid release parameters for lower priority, non-threatening targets. This may not be a wise alternative, but the process owner must be challenged to answer "why not?"

The immature targeting and BDA processes for Precision Engagement are gradually improving. For the network-centric warfighter, the risk of introducing network-centric hardware dependent on immature nodes for function must be recognized and managed. Hardware and technology may limit a node's maturity, but the most difficult challenge may be reorganization and doctrinal development in response to change. In addressing the transformation process, Admiral Cebrowski writes,

> 'In spite of a ponderous acquisition process, technology insertion is ahead of and disconnected from joint and service doctrine and organizational development. The problem is cultural and systemic. A process for the co-evolution of technology, organization, and doctrine is required.'[29]

To achieve co-evolution, doctrinal and organizational requirements and development must accompany the technology acquisition process.

Pitfall #4: Immature Links. Immature communication links can degrade or neutralize the effectiveness of a network-centric system. The target development process is plagued by competing stovepipe targeting systems that cannot share data or utilize similar file formats.[30] The result is repetitive manual entry of a twenty-digit alphanumeric target coordinate. The potential for error is significant.

In recent years, much effort has been devoted to the difficult problem posed by Time Sensitive Targets (TSTs). The focus of the effort is shortening the timeline from sensor to shooter, enabling the striker to engage the target in a limited window of opportunity. The DoD Kosovo After Action Report recommends in its Precision Engagement lessons learned,

> 'Continue to assess technologies that will ensure flexibility and enable all weather precision strikes, including on-board and off-board accurate targeting capability against fixed and mobile targets, that can be executed within minutes of target assignment.'[31]

A major shortcoming in the process today is our ability to transfer target data to the strike aircraft. In many cases the only means of transferring the twenty-digit alphanumeric target coordinate to a JDAM-capable aircraft is via voice radio, a prolonged and error-prone process. The Naval Strike and Air Warfare Center (NSAWC) has codified "standard operating procedures" for verification and read-back of coordinates for JDAM and other GGMs. Communication of one individual DPI takes several minutes. These procedures have been used routinely in Operation SOUTHERN WATCH (OSW) missions. Mature, automated links, which will shorten the time line and decrease susceptibility to errors, are in development.

The network-centric warfighter must recognize the importance of effective linking on a network of interdependent systems. Introduction of network-dependent hardware to a system with weak communication links results in degraded operations and potential failure.

As with critical nodes, critical links become a high value target for a potential adversary. Communication links in the network must be mature and robust.

Pitfall #5: Lost Accountability. Though an abstract concept, the pitfall of lost accountability has very real ramifications for the network-centric force of the future. In our platform-centric force, the platform owner has ultimate accountability for the performance of his platform. This accountability is a powerful tool in ensuring control of the platform's tremendous lethal force. The pilot has always been ultimately accountable for his weapons. If a pilot no longer has the capability of verifying weapon aim-points, is he responsible if they go to the wrong place? Who is ultimately accountable for bombing the Chinese Embassy? Shared accountability implies dispersed accountability, which, in truth, means accountability is non-existent. This characteristic is amplified by the imperative for "decisive speed" and "overwhelming operational tempo". Interdependent systems and shared awareness promote the dispersal of accountability for the employment of lethal force. A hypothetical fratricide incident can vividly illustrate this dilemma. Does the sensor node, which erroneously labeled a contact "hostile", bear full accountability for the fratricide even though he did not "pull the trigger?" More importantly, did the sensor node realize the weight of accountability? There is no easy solution to this problem. As specific cases are identified, the network-centric warfighter must apply effective doctrine to ensure managed accountability for lethal effects.

Conclusion

> "...the road to warfare based upon NCW needs to be richly populated with analyses and experiments in order to understand how we can reap the huge potential of NCW, while avoiding the pitfalls of unintended consequences."[32]

Analysis of the Joint Direct Attack Munition (JDAM) in the context of Network-Centric Warfare reveals both enormous potential and significant pitfalls. In the operational concept of Precision Engagement, JDAM has the capability to support high tempo massing of effects, geographic dispersal of forces, and reduced logistic footprints. Conversely, JDAM's shortcomings reveal some significant pitfalls, which the warfighter shall continue to face during the progressive transformation to a network-centric force.

The existence of non-redundant critical nodes in an interdependent networked system represents a serious vulnerability. The insertion of erroneous information in the network by either inadvertent or deliberate means presents another difficult challenge for the warfighter. The presence of a network guarantees more and quicker information, but it does not ensure better quality information without the implementation of safeguards. The introduction of network dependent hardware into a system of immature nodes and communication links has the potential to degrade effectiveness. Lastly, the dispersal of accountability in an interdependent network presents a challenge for the operational commander in establishing controls in the employment of lethal force.

The Network-Centric Warfare (NCW) transformation is happening today. "The inevitability of warfare in the information age is a reality - now is the time to grasp the implications and prepare."[33] Overcoming the inherent pitfalls is not an insurmountable challenge but an ongoing, deliberate exercise in experimentation, analysis, and adaptation.

> 'The future is bright and compelling, but we must still choose the path to it. Change is inevitable. We can choose to lead it or be victims of it.'[34]

Notes

[1] Arthur K. Cebrowski and John J. Garstka, "Network-Centric Warfare: Its Origin and Future," U.S. Naval Institute Proceedings, 124, no. 1 (January 1998): 29.

[2] Arthur K. Cebrowski, "Network-Centric Warfare: An Emerging Military Response to the Information Age," Lecture, 1999 Command and Control Research and Technology Symposium: 29 June 1999.

[3] General Accounting Office, Guided Weapon Plans Need to Be Reassessed (GAO/NSIAD-99-32), Report to Congressional Requesters (Washington, DC: December 1998), 21.

[4] General Accounting Office, Weapons Acquisition: Precision Guided Munitions in Inventory, Production, and Development (GAO/NSIAD-95-95), Letter Report (Washington, DC: 23 June 1995), 12.

[5] David S. Alberts, John J. Garstka, and Frederick P. Stein, Network Centric Warfare: Developing and Leveraging Information Superiority (Washington, DC: DoD C4ISR Cooperative Research Program, 1999), 94.

[6] Ibid.

[7] Ibid.

[8] Joint Chiefs of Staff, Joint Vision 2020 (Washington, DC: June 2000) 22.

[9] General Accounting Office, Guided Weapon Plans, 27.

[10] Ibid, 28.

[11] General Accounting Office, Operation Desert Storm Evaluation of the Air Campaign (GAO/NSIAD-97-134), Report to the Ranking Minority Member, Committee on Commerce, House of Representatives (Washington, DC: June 1997), 32-33.

[12] Ibid, 34.

[13] Ibid, 29.

[14] Ibid.

[15] Ibid.

[16] Federation of American Scientists, Joint Direct Attack Munition (JDAM) <http://www.fas.org/man/dod-101/sys/smart/jdam.htm> [20 January 2001].

[17] Air Force Operational Test and Evaluation Center, Joint Direct Attack Munition (JDAM) Multi-service Operational Test and Evaluation (MOT&E) Final Report (Kirkland AFB, NM: December 2000), C-16.

[18] Department of Defense, Report to Congress: Kosovo/Operation Allied Force After Action Report (Washington, DC: 31 January 2000), 60.

[19] Ibid, 97.

[20] Air Force Operational Test and Evaluation Center, C-34.

[21] General Accounting Office, Operation Desert Storm Evaluation of the Air Campaign, 132.

[22] Ibid, 128.

[23] Cebrowski and Garstka, 35.

[24] Air Force Operational Test and Evaluation Center, C-16.

[25] David Foxwell and Mark Hewish, "GPS: Is it Lulling the Military into a False Sense of Security?" Jane's International Defense Review, 31, no. 9 (September 1998): 37.

[26] Department of Defense, xx.

[27] Navy Warfare Development Command, Fleet Battle Experiment Bravo: Ring of Fire, Silent Fury, <http://www.nwdc.navy.mil/Products/FBE/bravo/bravo.htm> [19 January 2001].

[28] Department of Defense, 81.

[29] Cebrowski and Garstka, 35.

[30] Tony DeRossett, Eric Kamien, and Dolores Heib, "Challenges in Sharing Joint Targeting Information," A Common Perspective, 8, no. 2 (October 2000): 12-13.

[31] Department of Defense, 96.

[32] Alberts, Garstka, and Stein, 104.

[33] William K. Lescher, "Network-Centric: Is It Worth the Risk?" U.S. Naval Institute Proceedings, 125, no.7 (July 1999): 63.

[34] Cebrowski and Garstka, 35.

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